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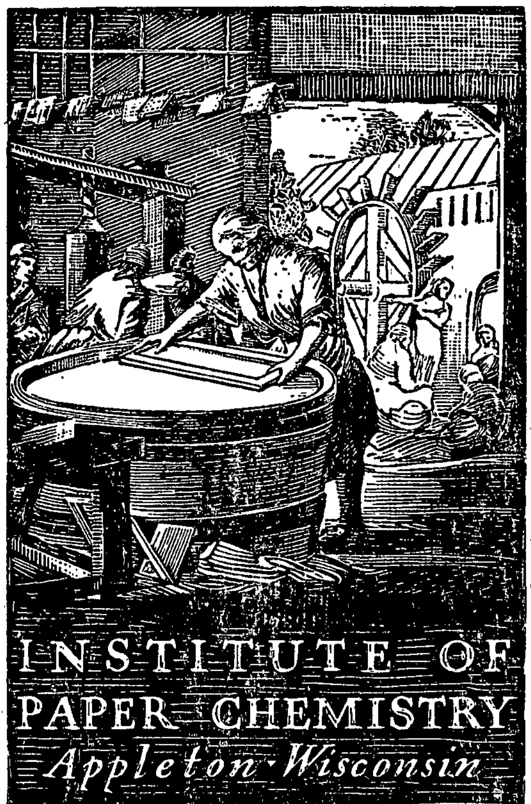

AN INSTRUMENTATION STUDY OF THE WEYCO GLUABILITY TESTER

Project 2697

Report One

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

November 1, 1967

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

At the request of the Fourdrinier Kraft Board Institute, the Institute carried out a limited instrumentation study of a tester (Weyco Gluability Tester) designed by the Weyerhaeuser Co. for the evaluation of corrugated board and linerboard in terms of case sealing potential. The first models of the tester were designed for portable field use and were manually operated. For laboratory testing, the tester design was modified to incorporate a motor to separate the adhered surfaces. The motorized tester was supplied to the Institute.

In brief, the test involves the application of adhesive to the surface of a specimen held in suitable clamps. After a prescribed interval of time, a second specimen is brought into contact with the adhesive-treated surface of the first specimen. The two board surfaces are held under pressure for a prescribed period of time, after which the force required to separate the adhered surfaces is measured.

The time periods and pressure can be varied to suit the needs of the user; however, the manufacturer suggests that the following conditions are generally suitable:

1. Adhesive application time (time between spreading of adhesive and application of pressure): 5 sec.
2. Time under pressure: 15 sec.
3. Pressure: 4.4 p.s.i. (10 lb. load on 2.25 in.^{2} area)

While both the amount and type of adhesive can be selected to meet specific needs, the evaluation at the Institute was restricted to the adhesive supplied with the tester (H. B. Fuller's No. 359). In all tests the 0.016-inch wire size Mayer rod supplied with the tester was used to meter the amount of adhesive.

The results obtained in this study are summarized below:

1. A calibration of the force gage indicated readings were within about ± 1.5 to 2.0% of the scale reading. Some operating difficulties were encountered with the gage; however, it is not felt that they were of a serious nature.

2. Using a linerboard sample supplied by the Weyerhaeuser Co., the Institute was able to obtain results in good agreement with results obtained by the Weyerhaeuser Co. The test variability in the Institute tests was, however, somewhat greater than was obtained by the Weyerhaeuser Co. For an average of 10 specimens for the linerboard sample used, the results indicated that the true average would be expected to fall within ± 4.9% (Weyerhaeuser) or ± 7.9% (Institute) of the sample average at the 95% confidence level.

3. When the application time (time between spreading adhesive and bringing surfaces together), time under pressure and pressure were varied, the time under pressure appeared to have far more influence on bond strength than the other two variables. On the average, a 1-sec. change in time under pressure caused a 4 to 6% change in bond strength. Therefore, this time must be carefully controlled by the test operator and may merit automated control.

4. Increasing test rate increased test readings. At the slowest speeds studied the motor stalled with the combined board sample used on this study.

This was not felt to be serious inasmuch as most users would operate at the faster speeds. In other phases of the study, it was observed that the motor tended to hesitate and did not smoothly separate the adhered specimen when the test loads were near 7 lb. or more. A motor with somewhat greater power would be helpful in this case.

5. When small amounts of "slack" were introduced in the clamping of the lower linerboard specimen, test results tended to decrease. Statistically significant reductions in bond strength were observed in some instances. It is believed this illustrates the need for operator care in clamping to avoid "slack".

6. Day-to-day reproducibility was studied over a period of 10 days using two materials. Three of the daily averages were outside 2-sigma control limits for the linerboard sample. Five of the daily averages were outside 2-sigma limits for the combined board sample. These results indicate that day-to-day variations were greater than would be expected on a statistical basis.

7. Increasing R.H. markedly decreased bond strength. A reduction in bond strength was also observed in going from 73 to 90°F. at 85% R.H.

8. A very limited trial was carried out to determine if the amount of adhesive applied was reasonably uniform from day to day. Only two trials were made and statistically significant differences in the amount of adhesive applied were obtained. Considerably more data would be required, however, to establish the "normal" variation in adhesive application.

INTRODUCTION

A common method of closure for corrugated containers involves sealing of the flaps. The case sealing operation can be a frequent source of complaints to the corrugating plant when satisfactory closures are not obtained in the case sealing process.

While the case sealing operation is simple in principle, the technical ramifications are great because many variables are involved. They may be grouped in four broad categories as follows: 1) The type of sealing equipment and operating conditions, 2) The characteristics of the adhesive; 3) The fabrication quality, container design, and moisture content of the board at time of sealing, and 4) the adhesion characteristics of the linerboard. Because of the many variables in each category and their interaction, it is often difficult in the field to relate case sealing difficulties to any particular factor or factors.

Test equipment to permit evaluation of the gluability of linerboard or combined board in the laboratory or field has been designed by the Weyerhaeuser Co. Morris (1) has described the equipment and presented information relative to (1) the effect of various test variables on results, and (2) the effect of various linerboard manufacturing variables on linerboard gluability.

Because of the potential utility of the tester in the analysis of gluability problems, a limited instrumentation study of the tester-hereafter termed Weyco Gluability Tester-was undertaken by the Institute under the auspices of the Fourdrinier Kraft Board Institute. The results obtained are summarized herein.

DESCRIPTION OF TESTER AND TEST PROCEDURE

Morris (1) described the tester and test procedure in detail. The following description is paraphrased from his paper and from the instructions accompanying the tester.

A photograph of the tester with linerboard clamps in place is shown in Fig. 1. The essential components of the tester are:

1. Adhesive application: a weighted Mayer rod--wire size 0.016 inch diameter--is used to spread the adhesive on one specimen surface.

2. Specimen clamps: Two pairs of clamps are supplied with the tester. One pair of clamps is designed to accommodate linerboard specimens while the other pair of clamps is designed to hold A, B, or C flute combined board specimens. The combined board clamps are shown in Fig. 2. The clamps may be interchanged relatively easily.

3. Compression section: A spring loaded bar is used to hold the adhered specimens together. The amount of pressure can be varied between 0 and about 13 p.s.i. (0 to 30 lb. on a 2.25 in.^{2} area) by adjustment of the spring.

4. Force measurement: A Chatillon push scale gage (Model DPP10) is used to measure the force required to separate the adhered specimens.

It should be mentioned that the first models of the tester were designed for field use and manually operated. For laboratory testing, the tester design was modified to incorporate a motor to separate the adhered sections. As shown in Fig. 1, the motorized tester was supplied to the Institute. The motorized unit could, however, be easily dismantled for field use.

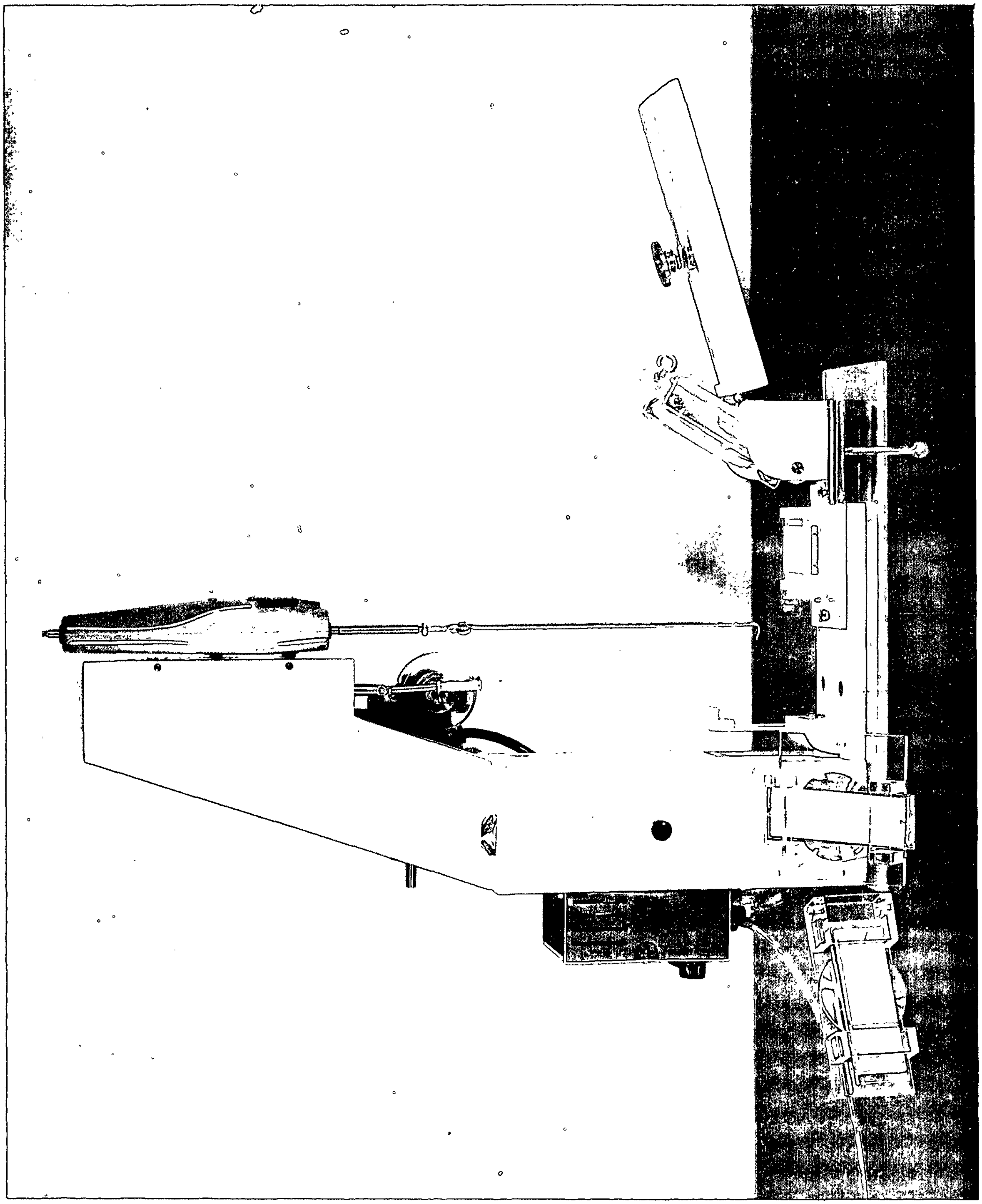

Figure 1. Weyco Gluability Tester with Linerboard Clamps in Place

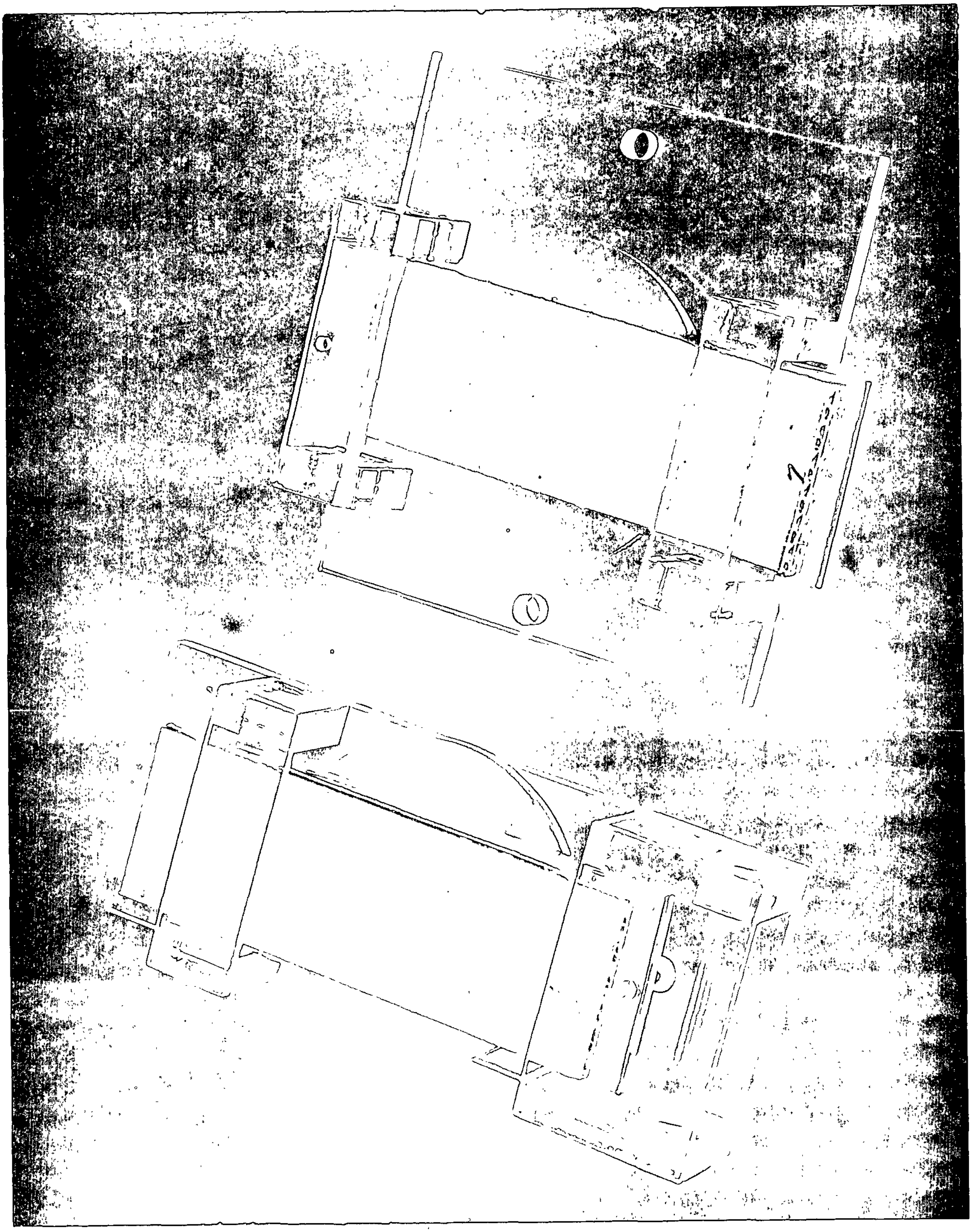

Figure 2. Combined Board Clamps

The procedure for adjusting the pressure on the specimen is described by Morris (1) as follows:

a. "Place samples in proper position in sample holders".

b. "Position push-pull gage in center of top hinge lever above the compression spring".

c. "Compress spring by applying force through the gage until the gage dial indicates the desired load pressure and the top hinge barely touches the latch."

d. "Tighten screw on top hinge to maintain this relative position of the cover to the bottom assembly of the unit."

Linerboard test specimens are cut to a size of 6 x 1-1/2 inches with the length parallel to the machine direction. Combined board specimens are cut to a size of 4-1/2 x 1-1/2 inches with the length perpendicular to the machine direction.

The procedure employed in making the tests is summarized briefly below:

1. Insert the specimens in the sample holders making sure that the specimens are oriented to test the desired surface. The linerboard specimens must be stretched tightly across the holder.

2. Apply a small bead of adhesive across the end of the sample in the bottom holder. (Note: A polyethylene bottle with a short length of glass tubing drawn out to have only a small opening is a convenient applicator.)

3. Spread the adhesive with the weighted Mayer rod applicator, "using the weight of the applicator only as the amount of pressure on the Mayer Rod" (1).

4. After a prescribed time interval, lower the upper specimen into contact with the lower specimen and close the hinged sample holder to apply pressure to the adhesive joint. A time interval of 5 sec. between application of adhesive and contact of the surfaces is suggested by Morris (1) though this may be varied to better simulate specific applications. A compression load of 10 lb. corresponding to a pressure of about 4.4 p.s.i. is recommended.

5. About 2 sec. prior to the end of the prescribed time period under pressure, start opening the hinged sample holder. Insert the hook of the force gage in the "eye" attached to the upper specimen holder and operate the motor to separate the adhered surfaces. The time under pressure is a critical variable and should be closely controlled. A time of 15 sec. was suggested by Morris (1).

6. Record the force required to separate the adhered surfaces to the nearest 0.1 pound.

CONDITIONING

All materials were preconditioned for at least 24 hours at less than 35% R.H. and 73°F. Except for one phase where the humidity and temperature were varied, all materials were conditioned for at least 48 hours at 50 ± 2% R.H. and 73°F.

STANDARD TEST CONDITIONS

In accordance with the work reported by Morris (1) the following "standard" test conditions were employed except in those instances where one or more of the variables were under study.

1. Application time: 5 sec. (time period started after spreading adhesive and ended when the specimens were brought into contact).

2. Pressure: 4.4 p.s.i. corresponding to a compression load of 10 lb.

3. Time under pressure: 15 sec. (the operator began to open the hinged cover 2 sec. prior to the expiration of the 15 sec. period as recommended by the manufacturer).

4. Test rate: 30 cycles/min.

ADHESIVE

For this instrumentation study H. B. Fuller's adhesive No. 359 was used. This is the adhesive recommended by the Weyerhaeuser Co. A representative of the H.B. Fuller Co. gave the following information regarding the adhesive:

pH	9.5-10.5
Viscosity, cp.	400
Solids, %	34

The Weyerhaeuser Co. forwarded a sample of adhesive with the tester. As discussed later in the text, initial test results were lower than expected and it was suspected that the adhesive had deteriorated in storage at the Institute. As a result, a new adhesive sample was procured from the Chicago office of the H. B. Fuller Co. More satisfactory test levels were achieved with the new sample and all testing in the study was performed using the new sample. Near the end of the study, a second batch of adhesive was ordered from the H. B. Fuller Co.

The pH and viscosities of the three adhesive batches are noted in Table I. As may be noted, the pH and viscosity of the original adhesive were near those specified by H. B. Fuller, however, low test results were obtained. The new adhesive (Batch 1) gave viscosities which were much higher than those specified by H. B. Fuller Co.; however, bond strength test results using Batch 1 were in good agreement with the values reported to the Institute by the Weyerhaeuser Co. The check on Sept. 18, indicates a change toward higher viscosity and low bond test results were obtained.

TABLE I

ADHESIVE CHARACTERISTICS

Sample Identification	Date	pH	Viscosity, cp. (No. 3 Spindle, 30 r.p.m.)
Original adhesive	7-19-67	9.0	392[a]
New adhesive Batch 1	7-19-67	9.3	1880
	7-31-67	9.1	2320
	8- 7-67	---	1680
	8-16-67	9.0	1200
	9-18-67	8.9	3550[b]
Batch 2	9-22-67	9.5	1120

[a]No. 2 spindle, 60 r.p.m.
[b]No. 3 spindle, 12 r.p.m.

DISCUSSION OF RESULTS

PART I. CALIBRATION OF CHATILLON PUSH-PULL GAGE

As mentioned previously, the tester employs a Chatillon push-pull gage with a maximum scale reading of 10 lb. to indicate the force required to separate the adhesive surfaces. In making a test the gage operates in the tension (pull) mode and is only used in the compression (push) mode when adjusting the compression load on the specimens.

The calibration of the gage was checked using the Baldwin-Southwark Universal Tester as reference. The results are summarized in Table II. In the more important tension mode, the Baldwin-Southwark and Chatillon gage readings differed by no more than 0.1 lb. (one gage dev.) up to 6 lb. Slightly greater deviations were noted above 6 lb. It appears that the Chatillon gage readings are accurate within about $\pm$ 1.5 to 2.0% of the scale reading. Somewhat greater differences were noted in the compression mode calibration though these would be less critical because the gage is only used in compression when changing the compression load applied to the specimens.

During testing, the operation of the gage was satisfactory with the exception that the switch which controls the maximum indicating feature of the gage would occasionally fail to lock the pointer at the maximum reading. In these instances, the test reading was lost. After some time, the operator overcame the problem by taking care to move the switch to its extreme uppermost position; however, if this difficulty were common, it could be an annoyance in regular testing. Also, using the standard test conditions, scale readings exceeding 10 lb. were occasionally obtained with the combined board sample used in the study.

This can be avoided by shortening the time under pressure; however, if such samples were frequently encountered, it would be desirable to have a force indicator with a greater scale capacity.

TABLE II

CALIBRATION OF CHATILLON GAGE

Tension Load, lb.			Compression Load, lb.		
Baldwin-Southwark	Chatillon Gage	Diff.	Baldwin-Southwark	Chatillon Gage	Diff.
1.10	1.10	0.00	1.00	0.98	-0.02
2.00	1.98	-0.02	2.00	1.95	-0.05
3.00	3.05	+0.05	3.00	2.85	-0.15
4.00	4.02	+0.02	4.00	3.90	-0.10
5.00	5.00	0.00	5.00	4.92	-0.08
6.15	6.05	-0.10	6.00	5.85	-0.15
7.00	6.85	-0.15	7.10	6.94	-0.16
8.00	7.87	-0.13	8.00	7.83	-0.17
9.10	8.95	-0.15	9.00	8.85	-0.15
10.00	9.85	-0.15	10.00	9.75	-0.25

PART II. COMPARISON OF 'GLUABILITY' RESULTS WITH WEYERHAEUSER CO.

When the tester was shipped to the Institute, the Weyerhaeuser Co. also included a quantity of H. B. Fuller's adhesive no. 359 and 50 packets of linerboard specimens for use in calibration. They also forwarded their test results on the linerboard sample. Initial test results obtained at the Institute with the calibration linerboard and the adhesive supplied with the tester averaged from about 2.6 to 4.1 pounds-well below the average of 4.37 lb. reported by the

Weyerhaeuser Co. As mentioned previously, it appeared that the adhesive was responsible for the low initial readings inasmuch as tests using a new adhesive supply were considerably higher.

The results obtained at the Institute with the new adhesive supply are shown in Table III together with the Weyerhaeuser Co. results. As may be noted, the overall average for the Institute and Weyerhaeuser Co. tests were in good agreement. Also, analyses of variance (see Table IV) were carried out for each laboratory to determine if the several averages within each laboratory were significantly different. The analyses indicated that the differences between averages within either laboratory were not statistically significant.

TABLE III

COMPARISON OF INSTITUTE AND WEYERHAEUSER CO. TEST RESULTS
USING CALIBRATION LINERBOARD

Laboratory	Trial No.	Bond Strength, lb. Average	Max.	Min.	Coeff. of Variation
Weyerhaeuser Co.	1	4.46	4.9	4.1	6.4
	2	4.40	4.8	4.0	5.7
	3	4.19	4.5	3.7	5.8
	4	4.30	4.7	3.9	6.2
	5	4.52	5.7	4.0	11.8
	Av.	4.37	--	--	7.2
Institute	1	4.43	5.5	4.0	11.6
	2	4.03	5.0	3.3	14.4
	3	4.50	5.4	4.0	9.8
	4	4.37	5.5	3.8	13.6
	Av.	4.33	--	--	12.4

Note: Each average is based on 10 tests.

TABLE IV

ANALYSIS OF VARIANCE OF INSTITUTE AND
WEYERHAEUSER CO. TESTS

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F
Weyerhaeuser Co.				
Between test averages	0.6872	4	0.1718	1.54[a]
Within test averages	5.0290	45	0.1118	
Total	5.7162	49		
Institute				
Between test averages	1.3048	3	0.4349	1.52[a]
Within test averages	10.3230	36	0.2868	
Total	11.6278	39		

$\sigma_0^2 + k\sigma_T$
σ_Θ^2

[a]Not significant at the 0.05 level:

$F_{0.05}$ (4, 45) = 2.59

$F_{0.05}$ (3, 36) = 2.87

With regard to test variability, it may be noted that the coefficients of variability for the Institute tests were generally higher than were obtained by the Weyerhaeuser Co. An F test of significance using the "within test average" variances in Table IV indicated that the Institute tests were significantly more variable than the Weyerhaeuser Co. results. Such differences in variability may arise due to operator technique, procedural variations, adhesive variations or instrumental differences. The Institute tests were carried out in accordance with the instructions accompanying the instrument. The adhesive batch was not the same as that used by the Weyerhaeuser Co. and it is not known whether the Weyerhaeuser Co. tests were carried out on the same instrument sent the

Institute. Therefore, while it may be stated that the variabilities are significantly different, the cause for the difference is not known.

In order to provide information relative to the precision of averages of ten readings for the sample, confidence intervals were calculated from the analyses of variance results. These are shown below.

	95% Confidence Interval	
	Pound	Percent
Weyerhaeuser Co. tests	± 0.21	± 4.9
Institute tests	± 0.34	± 7.9

For an average of 10 specimens from the 42-lb. linerboard sample, the results indicate that the true average would be expected to fall within ± 4.9% (Weyerhaeuser) or ± 7.9% (Institute) of the sample average at the 95% confidence level.

PART III. EFFECT OF PRESSURE, TIME UNDER PRESSURE, AND ADHESIVE APPLICATION TIME ON BOND STRENGTH

In performing the test, the operator must time two events, namely 1) the time interval between spreading the adhesive and bringing the surfaces into contact, and 2) the time under pressure. The specific times used can, of course, be selected to best fit particular applications; however, the following times were suggested for evaluating the relative performance of combined board:

1. Adhesive application time: 5 sec.
2. Time under pressure: 5 sec. at 4.4 p.s.i. (10-lb. compression load).

Morris (1) indicates that time under pressure has an important effect on the test load. When his results for four linerboard samples are averaged, an increase in bond strength from 3.46 lb. at 15 sec. to 6.53 lb. at 30 sec. is obtained.

This is an increase of about 89% for a 15-sec. change in compression time or about 6% per second change in compression time. Thus, even small variations in time under pressure between operators or laboratories may cause differences in test results. Morris also indicated that test loads increased as the compression load increased.

With the above in mind a factorial experiment was carried out to check the effect of the three variables. Tests were carried out at the following levels using a 42-lb. linerboard and a B-flute V3C combined board:

1. Pressure (P): 2.2 p.s.i. (5 lb.), 4.4 p.s.i. (10 lb.), 6.7 p.s.i. (15 lb.)
2. Time under pressure (TUP): 5, 10, 15, and 20 sec.
3. Adhesive application time (AT): 2, 5, and 8 sec.

Five specimens were tested at each condition.

The linerboard and combined board results are shown in Tables V and VI, respectively. The analyses of variance results are summarized in Table VII. In the case of the linerboard the results indicated that all three factors significantly affected the results. Examination of the test results and the F tests of significance indicates that time under pressure has far more influence on the results than either the pressure or application time. The combined board results were similar except that the pressure was not a significant factor for the board used herein.

The data in Tables V and VI were composited to show the general effects of the three factors. The composited values are summarized in Table VIII and illustrated in Fig. 3. As may be noted in the table, a change of 5 sec. in the time under pressure varied the bond strength by from about 20 to 30% for these materials and adhesive--or about 4 to 6% per sec. This seems to be in reasonable agreement with the results reported by Morris (1). Thus, this factor must be carefully controlled by the operator. An automated control of this variable would appear to be worthwhile.

TABLE V

EFFECT OF PRESSURE, TIME UNDER PRESSURE, AND ADHESIVE APPLICATION TIME ON BOND STRENGTH

(42-Lb. kraft liner)

Time Under Pressure, sec.	Bond Strength, lb.								
	2.2 p.s.i.			4.4 p.s.i.			6.7 p.s.i.		
	App. Time, sec.			App. Time, sec.			App. Time, sec.		
	2	5	8	2	5	8	2	5	8
5	2.28	2.26	3.00	2.30	2.70	2.68	2.58	2.56	3.02
10	3.02	3.58	3.68	3.44	4.12	3.84	3.84	3.82	4.40
15	4.74	4.66	4.76	5.34	5.52	5.64	5.02	5.00	5.00
20	6.40	6.48	6.68	6.42	6.46	7.34	6.54	6.40	7.06

Note: Each average is based on five determinations.

TABLE VI

EFFECT OF PRESSURE, TIME UNDER PRESSURE, AND ADHESIVE APPLICATION TIME ON BOND STRENGTH

(B-Flute combined board)

Time Under Pressure, sec.	Bond Strength, lb.								
	2.2 p.s.i.			4.4 p.s.i.			6.7 p.s.i.		
	App. Time, sec.			App. Time, sec.			App. Time, sec.		
	2	5	8	2	5	8	2	5	8
5	3.36	3.54	3.18	3.46	3.54	4.20	2.78	3.90	3.60
10	5.92	6.02	5.92	5.88	5.42	6.40	5.44	5.88	6.34
15	7.40	7.14	7.36	6.96	7.60	7.72	7.44	7.00	8.10

Note: Each average is based on five determinations. Tests were not performed at 20 sec. under pressure because loads frequently exceeded maximum scale capacity (10 lb.).

TABLE VII

ANALYSIS OF VARIANCE

Source of Variance	42-Lb. Kraft Linerboard			B-Flute V3C		
	Degrees of Freedom	Mean Square	F	Degrees of Freedom	Mean Square	F
Between pressures (P)	2	2.233	5.394[b]	2	0.250	0.549
Between time under pressure (TUP)	3	136.529	329.780[b]	2	174.781	384.134[b]
Between application times (AT)	2	2.920	7.053[b]	2	2.515	5.527[b]
P x TUP interaction	6	0.605	1.461[a]	4	0.268	0.589[a]
TUP x AT interaction	6	0.350	0.845[a]	4	0.355	0.780[a]
P x AT interaction	4	0.183	0.442[a]	4	0.945	2.077[a]
P x TUP x AT interaction	12	0.182	0.440[a]	8	0.562	1.235[a]
Residual	144	0.414	--	108	0.455	--

[a]Not significant at the 0.05 level.
[b]Significant at the 0.01 level.

TABLE VIII

COMPOSITED DATA SHOWING EFFECT OF TIME UNDER PRESSURE, APPLICATION TIME AND PRESSURE

		Linerboard		Combined Board	
Variable	Level of Variable	Bond Strength, lb.	Diff., %[a]	Bond Strength, lb.	Diff., %[a]
Time under pressure	5 sec.	2.60	-48.8	3.51	-52.6
	10 sec.	3.75	-26.2	5.91	-20.2
	15 sec.	5.08	--	7.41	--
	20 sec.	6.64	+30.7	--	--
Application time	2 sec.	4.33	- 2.9	5.40	- 2.9
	5 sec.	4.46	--	5.56	--
	8 sec.	4.76	+ 6.7	5.87	+ 5.6
Pressure	2.2 p.s.i.	4.30	- 7.5	5.54	- 2.6
	4.4 p.s.i.	4.65	--	5.69	--
	6.7 p.s.i.	4.60	- 1.1	5.61	- 1.4

[a]Based on standard test condition as reference.

In Table VIII differences in application time were less critical--at least for these materials, adhesive, etc. A change in time of 3 sec. varied results by from about 3 to 7%-or from about 1 to 2.3% per sec.

As may be seen in Table VIII, varying the pressure had a small effect on the bond strength for these samples and adhesive.

PART IV. EFFECT OF TEST RATE

A limited study of the effect of test rate in bond strength was carried out using a 42-lb. kraft linerboard and a B-flute V3C combined board. Test rates were varied from 10 to 30 cycles per minute. Higher speeds were not readily attainable because the motor recycled, continuously.

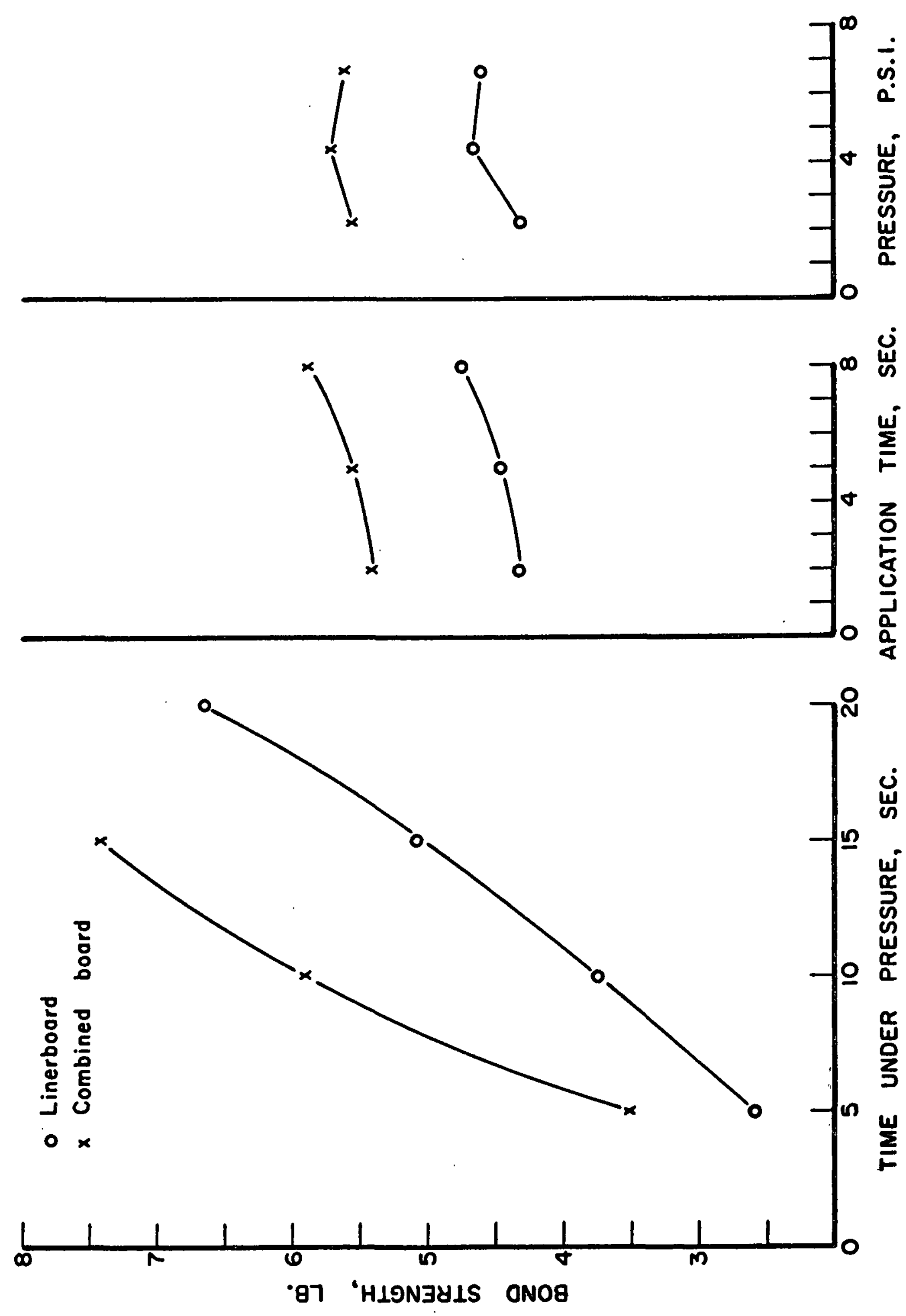

Figure 3. Effect of Time Under Pressure, Application Time, and Compression Load (Based on Composited Data)

The results are summarized in Table IX. As may be noted, decreasing the test rate from the standard rate (30 cycles per minute) resulted in lower bond strength. At the lowest speed studied--10 cycles per ~~second~~ minute--the motor stalled when the combined board sample was evaluated. However, this would probably be no real problem, as most users will probably employ the higher speeds.

TABLE IX

EFFECT OF TEST RATE

Test Rate, cycles/min.	Bond Strength, lb. 42-lb. Kraft Liner Av., lb.[a]	42-lb. Kraft Liner Diff., %[b]	B-Flute V3C Av., lb.[a]	B-Flute V3C Diff., %[a]
10	4.00	-23.4	--[c]	--
20	4.60	-11.9	7.14	-9.6
30	5.22	--	7.90	--

[a]Each average is based on five determinations.
[b]Based on standard rate of 30 cycles/min.
[c]At this speed, the motor had insufficient power to separate the adhered surfaces.

PART V. LINERBOARD SPECIMEN CLAMPING

The linerboard clamps are designed to permit tautly stretching the specimens over the test area. General observations during the course of the study indicated that the clamps were easier to use with lighter weight boards such as 26 or 42-lb. liner. It is more difficult to insert heavier weight liners, e.g., 90 lb., without introducing creases in the test area. In general, it is also felt that the operator should exercise care to avoid contacting the test surfaces with his hands as perspiration or oils from the skin could affect the adhesive receptivity and subsequent bond strength determination.

When inserting the specimen in the clamps, the operator must take care that no slack is left in the specimen. Because this operation requires some care, it was believed desirable to make a limited study of the effect of "slack" in the specimen after clamping on test results. To introduce controlled amounts of "slack" a spacer rod of known diameter was placed on the lower clamp across the center of the test area. The specimen was then inserted in the holder and tautly clamped so the specimen was stretched over the rod. After clamping, the rod was removed. Rod diameters of 0.122, 0.188, and 0.250 inch were employed. Thus, the above procedure introduced small controlled amounts of slack in the lower specimen; the upper specimen was clamped in the normal manner.

The results obtained with these linerboard grades are summarized in Table X. In general, the effect of increasing amounts of "slack" was to lower test results though the differences were statistically significant in only three instances. It should be noted that the test variability was very high on these tests--which made the statistical comparisons rather insensitive.

PART VI. DAY-TO-DAY REPRODUCIBILITY

For most tests it is highly desirable that the results be reproducible over considerable periods of time. To evaluate this aspect of tester performance, two materials--a 42-lb. kraft liner and a B-flute V3C combined board--were evaluated on each of 10 successive days. Ten specimens of each sample were evaluated on each day. The standard test conditions--5-sec. application time, 10-lb. compression load, and 15 sec. under pressure--were employed with the linerboard sample. In the case of the combined board sample, it was found necessary to reduce the time under pressure to 10 sec. to avoid exceeding the maximum scale reading (10 lb.). The same operator performed all tests.

TABLE X

EFFECT OF "SLACK" DURING SPECIMEN CLAMPING

Material	No Spacer (Control)		Bond Strength, lb. 0.122 In. Spacer[a],			0.188 In. Spacer[a],			0.250 In. Spacer[a],		
	av.	ν^e	av.	ν^e	Diff., %[b]	av.	ν^e	Diff., %[b]	av.	ν^e	Diff., %[b]
26-Lb. kraft	3.77	18.8	3.82	14.4	+1.3	3.74	21.9	-0.8	3.39	12.4	-10.1
42-Lb. kraft	5.25	18.5	4.76	9.9	-9.3	4.20[d]	12.4	-20.0	4.12[d]	17.7	-21.5
90-Lb. kraft	6.37	35.5	6.30	29.0	-1.1	5.91	25.2	-7.2	4.48[c]	12.9	-29.7
Composite	5.13	--	4.96	--	-3.3	4.62	--	-9.9	4.00	--	-22.0

[a]Round spacer placed under specimen on lower clamp only. After clamping the specimen, the spacer was removed to induce slack in specimen.

[b]Based on results with no spacer as reference.

[c]Significantly different from control at the 0.05 level.

[d]Significantly different from control at the 0.01 level.

[e]Coefficient of variation.

Before the trials were initiated, tests were made using the linerboard sample supplied by Weyerhaeuser Co. Averages of 4.38 and 4.25 lb. were obtained-in good agreement with the previous results cited in Part II.

The day-to-day test results are summarized in Table XI and graphically illustrated in Fig. 4. For the 42-lb. liner sample, the daily averages varied from 3.84 to 4.99 lb. with a grand average of 4.50 lb. Three of the averages fell outside 2-sigma control limits and one average fell outside 3-sigma limits. For the combined board sample, the daily averages ranged from 5.5 to 7.2 lb. with a grand average of 6.3 lb. Five of the ten averages were outside 2-sigma control limits and four of the five were outside 3-sigma control limits. In general, the above results indicate that day-to-day variations were greater than would be expected on a strict statistical basis.

Several sources of variation might cause such day-to-day shifts in test level. They include variations in material, operator technique, adhesive and instrument. The materials used were carefully randomized before beginning the testing; therefore, it appears unlikely that material variations could cause the frequent shifts in test level. The checks of the tester with the Weyerhaeuser calibration material which were made before beginning the testing were in good agreement with previous results. This indicates that initially both adhesive and tester were in satisfactory condition. Unfortunately, similar checks were not made during or after the test period. However, any deterioration of the adhesive during the test period would be expected to result in a sustained gradual or sudden shift in test level--probably to lower test values. Thus, it seems unlikely that deterioration of the adhesive would cause both high and low test values during the 10-day test period. The above reasoning suggests--but does not prove--that variations in operator technique or instrumental factors may have been

TABLE XI

REPRODUCIBILITY OF TEST RESULTS OVER A 10-DAY PERIOD

	Bond Strength, lb.			
	42-Lb. Kraft Liner		B-Flute V3C	
Day	Av.[a]	Range	Av.[a]	Range
1	4.88[b]	1.6	6.07	1.4
2	4.44	1.7	5.98	3.6
3	4.77	1.9	6.09	1.6
4	4.64	2.0	6.51	2.4
5	4.29	1.1	6.84[b]	2.6
6	3.84[c]	0.8	5.48[c]	2.0
7	4.50	2.9	5.54[c]	0.9
8	4.48	1.6	7.00[c]	1.7
9	4.99[b]	2.1	6.46	0.5
10	4.14	2.0	7.21[c]	1.4
Av.	4.50	1.77	6.32	1.81
2-Sigma limits on $\underline{X}$ - Upper	4.86		6.96	
Lower	4.14		5.95	
3-Sigma limits on $\underline{X}$ - Upper	5.05		6.88	
Lower	3.95		5.76	
Population standard dev.	0.58		0.59	
Coeff. of variation	12.9		9.3	

[a]Each daily average is based on 10 specimens.

[b]Outside 2-sigma limits.

[c]Outside 3-sigma limits.

Note: The combined board testing was initiated on the day the fifth set of linerboards was tested.

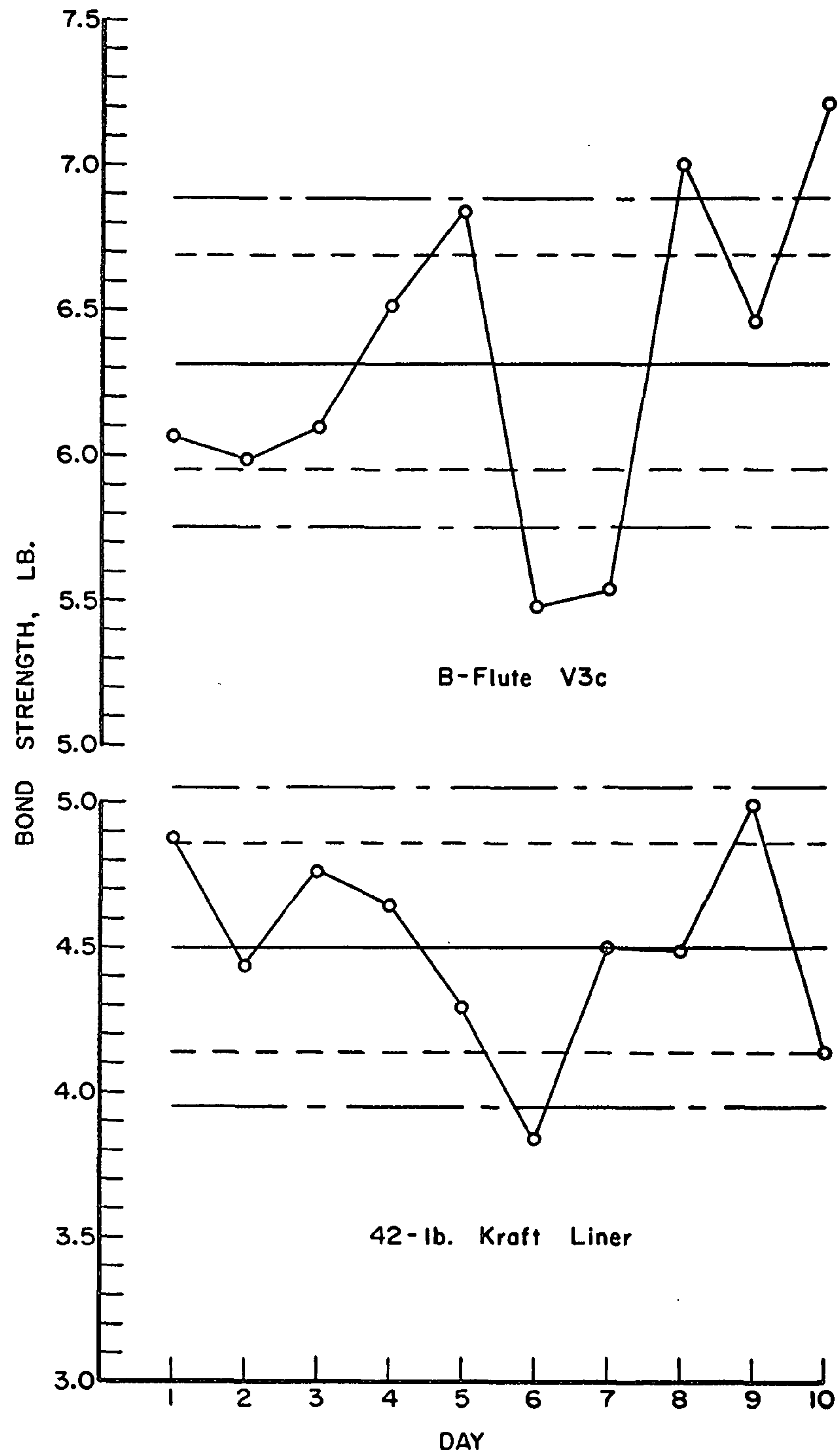

Figure 4. Comparison of Test Results Over a 10-Day Period

responsible for the rather erratic shifts in test level. Opposed to this line of reasoning is the fact that the Institute was able to obtain results in good agreement with the Weyerhaeuser Company using the calibration sample supplied with the instrument.

It may be remarked that all tests at the Institute were conducted by one operator. This was desirable when studying the instrumental or procedural factors which affect the test results. Additional work might be warranted to provide information relative to the differences in test results associated with different operators.

Briefly summarizing the above, the test data exhibited greater variations from day to day than would be statistically expected. The cause of these variations is not known. For this reason it suggests that differences in results obtained over considerable periods of time should be interpreted cautiously.

PART VII. EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY

The moisture content of the paperboard at time of gluing would be expected to have a major effect on the bonding strength. Morris (1) evaluated four linerboard samples at moisture contents of 7, 9, 11, and 15%. His average results indicate reductions in bond strength of about 33, 40 and 81% at 9, 11, and 15% respectively, as compared to the bond strength at 7% moisture content.

For this study, one sample of 42-lb. kraft linerboard was evaluated at 10, 50 and 85% R.H. at 73°F. and at 85% R.H. and 90°F. Five tests were made in each atmosphere after conditioning the paperboard for at least 48 hours in the specified atmosphere. Also, at 90°F., the adhesive was placed in the test atmosphere 24 hours prior to carrying out the tests.

The results obtained are summarized in Table XII. As may be noted, increasing R.H. markedly lowered the test results in agreement with the results cited by Morris (1). The tests at 73°F. and 90°F. (both at 85% R.H.) also indicated that temperature may affect bond strength as evaluated herein. Thus, moisture content and temperature appear to be factors to be considered in "field" use of the instrument (portable model) as well as in the case sealing operation itself.

TABLE XII

EFFECT OF R.H. AND TEMPERATURE

(42-Lb. kraft linerboard)

R.H., %	Temp., °F.	Bond Strength, lb. Max.	Min.	Av.	Diff., %[a]
10	73	7.3	5.4	6.46	+70.9
50	73	4.3	3.2	3.78	--
85	73	1.7	1.3	1.40	-63.0
85	90	1.0	0.9	0.94	-75.1

[a]Based on results at 50% R.H., 73°F. as reference.

PART VIII. ADHESIVE APPLICATION UNIFORMITY

One factor which may involve much operator technique is adhesive application. This requires that the operator draw a weighted Mayer rod across the specimen surface to spread the adhesive. Variations in techniques from operator to operator and from time to time may introduce variations in test results. A very limited trial was made with one operator to determine what the variation in adhesive film would be on two successive days. The following procedure was employed to determine the dry adhesive pickup:

1. On each day 10 specimens were carefully weighed and their dimensions measured to determine their initial weight per unit area.

2. The specimens were then inserted in the lower clamp and adhesive was applied in the recommended manner.

3. The specimens were removed from the clamp, allowed to dry for 24 hours at less than 35% R.H., 73°F. and reconditioned for 48 hours at 50 ± 2% R.H. and 73°F.

4. A 1.50-inch long strip was then cut from the central region of the specimen where the adhesive was spread. This was weighed and the dry weight of adhesive was calculated.

The average adhesive dry pickups on the two trials are shown in Table XIII. As may be noted, the average results for the two days were statistically different and such variations may be one factor which could give rise to day-to-day variations in test results. However, considerably more data would be required to determine what variations would be normally encountered from day to day or between operators.

TABLE XIII

ADHESIVE APPLICATION UNIFORMITY

	Trial 1 ($\underline{N}$ = 10)	Trial 2 ($\underline{N}$ = 10)
Dry adhesive pickup, g./in.^{2}		
Average	0.0142	0.0103
Coefficient of variation	14.2	18.3

Note: Difference in pickup significant at the 0.01 level.

PART IX. EFFECT OF BASIS WEIGHT AND LINERBOARD STIFFNESS

A limited series of tests were carried out to evaluate the performance of the tester over a range of linerboard basis weights. For this purpose, 26, 42, and 69-lb. liner were evaluated using the standard test conditions. The board samples were taken from materials in stock. While they were manufactured by one company, their adhesive receptivities, etc., could be quite different. Therefore, differences in test results between the grades tested could arise either from differences in gluability or weight effects such as stiffness.

The results obtained are summarized in Table XIV. As may be noted, the bond strength increased markedly in going from the 26 to 69-lb. weight. In an effort to determine if this change was caused by differences in receptivity or liner stiffness, a series of tests were carried out in hand-laminated boards made up as follows:

1. 26-lb. laminated to 26 lb. using Fuller no. 359 adhesive.
2. 26-lb. laminated to 42 lb. using Fuller no. 359 adhesive.
3. 26-lb. laminated to 69 lb. using Fuller no. 359 adhesive.

Tests were carried out on the laminated boards using the 26-lb. surface as the test surface. Thus, the stiffnesses of the laminated boards were quite different due to the differences in weight while the adhesive receptivity was held constant except insofar as migration of the laminating adhesive might affect the subsequent bond strength tests.

The results obtained are summarized in Table XV. In general, the differences between laminated grade weights were relatively small. This suggests that the basis weight differences noted in Table XIV were probably caused by differences in receptivity of the three grade weight linerboards.

TABLE XIV

EFFECT OF BASIS WEIGHT ON BOND STRENGTH

Test No.	Bond Strength, lb. 26-Lb. Weight	42-Lb. Weight	69-Lb. Weight
1	2.5	3.3	4.2
2	2.6	4.2	4.2
3	2.7	3.7	5.4
4	2.9	4.0	5.0
5	2.5	3.6	4.9
Av.	2.64	3.80	4.74

TABLE XV

EFFECT OF LINERBOARD STIFFNESS ON BOND STRENGTH

Test No.	Bond Strength, lb. 26-Lb. Lam. to 26-Lb.		26-Lb. Lam. to 42-Lb.		26-Lb. Lam. to 69-Lb.	
	Trial 1	Trial 2[a]	Trial 1	Trial 2[a]	Trial 1	Trial 2[a]
1	3.2	3.0	4.3	2.8	5.0	3.5
2	4.3	3.1	5.1	2.8	3.7	2.2
3	3.6	3.3	4.7	3.2	4.0	3.4
4	4.3	2.2	3.8	2.5	3.3	3.2
5	3.7	2.7	4.3	2.7	4.0	3.4
Av.	3.82	2.86	4.44	2.80	4.00	3.14
Composite av.	3.34		3.62		3.57	

[a]The difference in level between Trials 1 and 2 was probably caused by a change in adhesive characteristics between trials.

LITERATURE CITED

1. Morris, R. M., Jr. Controlling the gluing process in corrugated container case sealing. Tappi 50, no. 5:49-56A(May, 1967).

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